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NICKEL/CADMIUM AIRCRAFT BATTERIES: PRACTICAL RESISTANCE MEASURE--ETC(U)

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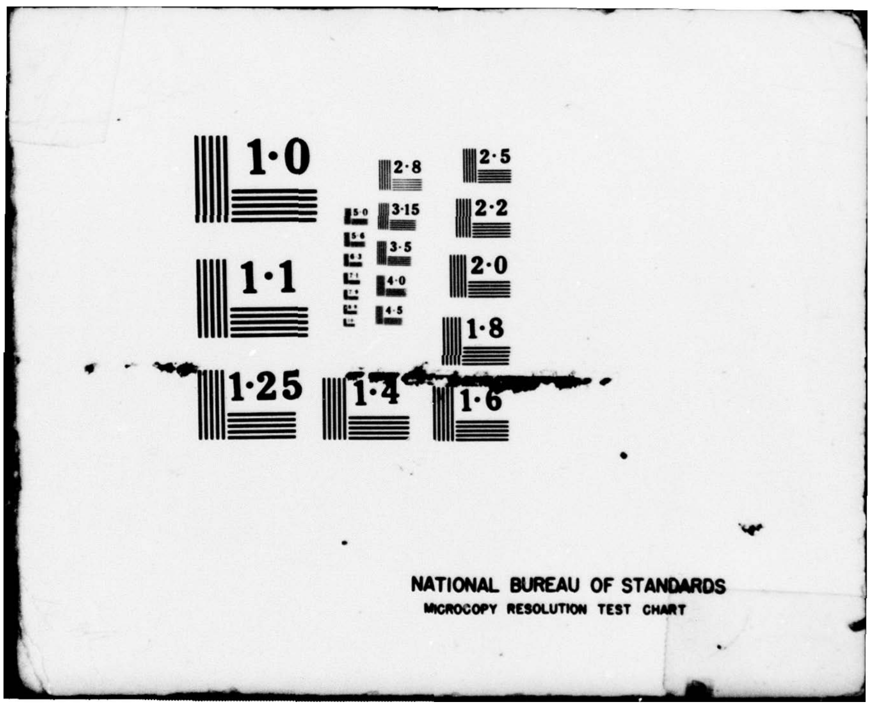
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6 NICKEL/CADMIUM AIRCRAFT BATTERIES:
PRACTICAL RESISTANCE MEASUREMENTS

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ABSTRACT

The measurement of resistance in nickel/cadmium aircraft batteries can be very useful in assessing quality for high rate applications and in identifying various problems. Frequently, measurements on individual cells are required. For many purposes, measurements can easily and rapidly be made with a milliohmmeter. However, for some purposes determination from appropriate voltage and current measurements may be preferred. This paper discusses both methods and elaborates associated precautions and interpretations. Examples from laboratory experiences are given.

RÉSUMÉ

Les mesures de résistance peuvent se révéler fort utiles à l'évaluation de la qualité des batteries d'aviation au nickel-cadmium appelées à débiter des courants élevés et à la détermination de la nature de leurs défauts. A cet égard, c'est souvent la résistance des éléments qu'il faut mesurer. Dans bon nombre de cas, on se servira d'un milliohmmètre pour exécuter les measures facilement et rapidement. Mais il est parfois préférable de calculer la résistance à partir de mesures de tension et de courant. Nous présentons les avantages et inconvénients des deux méthodes, précisons les précautions à prendre pour chacune et indiquons comment interpréter les résultats, à partir de résultats obtenus en laboratoire.

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INTRODUCTION

The performance of a battery in high rate applications is greatly influenced by the internal resistance of the battery. In aircraft engine cranking, for example, the resistance of the starter circuit may be considerably less than that of the battery. The magnitude of the current obtained is therefore more limited by the battery resistance than by the load.

Inadequate performance may result from unsuitable design of cells and intercell connections, and/or from inadequate maintenance and deteriorated cells. Resistance measurements are particularly useful in detecting such problems since other battery shop procedures may not draw attention to them. However, the making and interpretation of resistance measurements on batteries and on individual cells present problems not encountered in the more common areas in the electrical field.

This paper discusses two practical methods of making resistance measurements on flooded nickel/cadmium aircraft batteries and is based on the experiences in this laboratory. Typical data are presented.

RESISTANCE IN BATTERIES

Electrical resistance is loosely described as the difficulty an electrical charge experiences in moving from one location to another. More explicitly, resistance is defined by Ohm's Law and is generally considered in connection with large numbers of charges flowing as "current". By this definition, the resistance $R = V/I$, where I is the magnitude of the current flowing through a given path or configuration of paths, and V is the potential drop across the path or combination of paths, resulting from the flow. This definition applies to current flow through cells in a battery in the same way as it does elsewhere. However, in attempting to make measurements of these quantities on a cell, two problems arise: (a) the cell generates a (variable) voltage, so the terminals of the cell show this voltage combined with the voltage drop in the resistance, and (b) the combination of paths followed by the current through the cell is unknown and variable.

As a result of these difficulties, measurements sometimes include other factors in addition to resistance and are either loosely referred to as "resistance" or are given special definitions. For example, at the 1965 meeting of the International Electrotechnical Commission, the report of a Working Group on batteries defined internal resistance as the sum of all factors which decrease terminal voltage when increased current is taken from a battery. "Depending on the conditions of measurement, the observed resistance values will include in a varying relationship to one another an ohmic component, a capacitive component, and a polarization effect" (1).

While departure from the precise definition of resistance, such as the above, may at times be convenient, at other times further complications arise. For example, when the current, I, flows through a resistance, R, the heat generated is given by I^2R. This is true, of course, only if the value of R is true, i.e. it includes only the "ohmic" factor referred to above (2). Also the "varying relationship" between the somewhat unrelated factors in the above definition make practical use of the "measurement" difficult.

This paper deals with the measurement of resistance as defined by Ohm's Law and is concerned with the DC uses of aircraft batteries. Other applications, such as the use of the battery as a filter component, would, of course, also require consideration of the capacitive and inductive reactances (3,4). The reactances are of concern here only to the extent that they may complicate the making of the resistance measurements.

It is convenient in the discussions below to use the term "electromotive force" as frequently used in physics and electrical engineering (see for example the Encyclopaedic Dictionary of Physics, edited by J. Thewlis, 1962) to represent the full voltage generated by a cell or battery at any given instant. This voltage can be observed at the terminals only if no voltage drop takes place within the cell or battery, i.e. if no current is flowing (or if the current approaches zero).

MEASUREMENT DIFFICULTIES

The making and interpretation of battery and cell resistance measurements on nickel/cadmium batteries involves the following:

(a) The generation of electromotive force (emf) by the cell makes it necessary either to use measurement techniques which are compatible with these direct current (dc) conditions, or to use suitable alternating current (ac) coupling and measurement techniques.

(b) The voltage across the terminals of a cell is a combination of the emf of the cell with a voltage drop due to any current flowing through the internal resistance of the cell.

(c) The emf of a cell is not necessarily constant and varies with factors, such as, the direction and magnitude of current flowing, state of charge, generation and presence of gas in the cell, electrolyte concentration, state and nature of the plates in the cell, recombination rates (if any) of oxygen and cadmium, temperature, etc.

(d) When a discharge is initiated, the initial current surge may be greatly influenced by the charge stored in the double layer and by circuit parameters, both internal and external to the cell, particularly by inductive and capacitive reactances.

(e) The current distribution in a cell may change significantly during the course of extensive charge or discharge, with temperature changes, with the conditions of the electrolyte and of the plates, etc. The internal resistance associated with one pattern of current distribution is not necessarily identical with that of another (5,6).

(f) The resistance of any given path in a cell may change as a result of the state of charge, the condition of the plates (large or small crystal structure, presence of passivation, etc.), the condition of the electrolyte (KOH concentration, carbonate concentration, etc.), the temperature, the presence of gas bubbles in the electrolyte and pores of the plates and separators, etc.

(g) Temperature effects may have implications both directly, by changing the resistance of the components in the current path, and indirectly by causing changes in current distribution. At lower temperatures the resistance of the electrolyte increases but the resistance of the metallic part of the path decreases.

(h) During overcharge, if oxygen (generated at the positive plate) reaches and reacts with the cadmium plate, changes in current distribution and in local temperature are caused. These changes cause corresponding resistance changes and emf changes (7).

In spite of the above complicating factors, measurements of resistance for practical purposes can readily be made.

THE USE OF RESISTANCE MEASUREMENTS

Resistance measurements are particularly valuable in maintenance procedures for batteries to be used in high rate applications, such as engine cranking, and for batteries to be used at medium rates at very low temperatures. Resistance measurements and concepts are also useful in research work, in the design and development of batteries, for quality control, qualification testing, etc. (For example, a battery with relatively high

resistance might more readily pass a float charge test because of reduced current flow when charged at a fixed voltage, but the battery would be poorer for high rate applications.)

Examples experienced in the laboratory are discussed in later sections of this paper.

METHODS OF RESISTANCE MEASUREMENT

Two useful methods of measuring resistance of nickel/cadmium cells and batteries have been found convenient in the laboratory. One of these requires only the use of a commercial milliohmmeter and provides a simple rapid means for making the measurements under field conditions. The second method is more involved. It requires suitable equipment for carrying out high rate discharges and for recording "instantaneous" voltages and current magnitudes (chart recorders, for example). The resistances must then be calculated from the recorded traces. With the milliohmmeter mentioned above, the resistance readings appear immediately on the face of the meter.

Obviously, of the two methods, the milliohmmeter provides the much simpler approach. However, the results given by the two methods do not necessarily agree with each other. This is discussed below and it is suggested that, properly interpreted, both methods have their applications.

THE MILLIOHMMETER METHOD

The following description relates specifically to the Hewlett Packard model 4328A milliohmmeter. This unit displays the measured resistance on a moving pointer type meter. The 11 selectable ranges cover full scale sensitivities from 1 milliohm (mΩ) to 100Ω. Four leads are provided to connect to the item to be measured. Two of these provide the test current which consists of a 1000 Hz sine wave of constant magnitude for each range. The maximum amplitude is 150 mA on the 1 mΩ range, and the minimum, on the 100Ω range, is 1.5 μA. The other two leads sense the voltage developed by the test current. The instrument determines the resistance from this by use of the in-phase components, hence measures pure resistance in the presence of reactances. Both sets of leads are ac coupled so measurements can be made directly on batteries without complications due to the battery emf's. An electrical output is available for driving a recorder.

In the laboratory it was found desirable to modify the connectors supplied with the instrument. This is discussed in Appendix I.

Since the test signal used by the milliohmmeter consists of a 1000 Hz sine wave of very low amplitude, the resistance indicated applies to the path over which this type of signal flows through the cells. This path may differ from the path of the dc current normally of interest, and it is found that normally the indication given by the milliohmmeter is different than that obtained by the method described in the next section. However, the milliohmmeter measurements can nevertheless show defects such as deteriorated construction, poor connections, etc., and give valid comparative data from cell to cell. Because it is simple to use and is inexpensive compared to the alternative method, the milliohmmeter is a valuable instrument for battery care and investigation.

Comparisons between results obtained by the two methods are given in a later section.

HIGH RATE DISCHARGE METHOD

This method, also referred to as the $\Delta V/\Delta I$ method, consists of doing a high rate discharge and calculating the resistance from the "instantaneous" changes in voltage and current when the discharge is initiated and/or terminated. The term "high rate" implies that the current during the discharge is high enough to give a sufficiently high IR drop in the cell or battery to permit accurate measurements to be made for the intended purpose (a cell may have an internal resistance of 0.5 mΩ so only a 0.5 mV drop for 1A current change results). In practice a discharge of several hundred amperes is convenient for 22-Ah and 34-Ah cells. Since only the initiation and termination data are used, only a few seconds of discharge are required. Thus less than 1 Ah of the battery capacity need be discharged in any one measurement.

If all the cells in a battery (19 in a typical aircraft battery) are to be individually measured, of course, it is necessary either to have available large quantities of recording equipment or to carry out repeated discharges to obtain the data for all the cells. This, in addition to the facilities for carrying out the high rate discharges themselves makes this a more expensive and time consuming method than the one which uses the milliohmmeter. However, this method gives the true resistance of the paths actually applicable to the high rate discharge, and is frequently the quantity of interest.

It is necessary in this method to adequately provide for the fact that the calculations are based on the changes in voltage due only to the change in current through the applicable resistance. These values are referred to above as the "instantaneous" changes to emphasize that none of the changes are due to other factors which alter the voltage after the current is either initiated or terminated. Additional complications arise in practice due to reactive components in both the cells under measurement and the external circuitry. In particular, inductive effects cause large overshoots at switching times, and the switching itself may be complex.

The problems arising from the above complications can for practical purposes be minimized without serious difficulty. Details observed by use of a storage oscilloscope in the laboratory are shown in the following series of photographs to illustrate the problems.

Figure 1 shows the initiation of a discharge of about 100A from a 22-Ah nickel/cadmium cell. The circuit was closed by a solenoid operated switch. The switch "bounced" sufficiently to close the circuit three times before it finally remained closed. Each time, inductive effects caused voltage surges in both directions, but within two milliseconds all effects due to both switch bounce and reactance had disappeared.

Figure 2 shows a similar initiation, but a silicon controlled rectifier (SCR) replaced the mechanical switch. This eliminated the switch bounce but the reactance effects remain and require about one millisecond to subside.

Figure 3 shows the termination of a discharge. There are no effects due to switch bounce but surges due to reactance are again present for a fraction of a millisecond.

Figure 4 shows a discharge on a much slower time scale so that the whole four second pulse is visible. The effects of reactance at the initiation and termination cannot be seen due to a reduction in oscilloscope brightness to accommodate the lower sweep rate. During the course of the discharge, the voltage decreased rapidly at first and then more slowly. At termination the voltage increased "instantaneously" by about the same amount as the drop at initiation. However, the absolute voltage reached on termination was lower than the initial voltage by the amount of the gradual drop during the pulse. Subsequently, the voltage slowly recovered to approximately its original value.

From the above it may be seen that changes in emf take place during and after the discharge but each of the changes occur sufficiently slowly to be distinguished from the IR voltage drop. This is so even when it is necessary to allow time for the decay for reactance effects. It may be seen also, from Figure 4, that a recording of ΔV and ΔI suitable for use in determination of R may be obtained by use of a strip chart recorder having a response time of about 0.5 seconds.

COMPARISON OF THE TWO METHODS

From the above descriptions it is seen that the $\Delta V/\Delta I$ method gives a "true" measurement applicable in high rate battery performance, but is a cumbersome method to use and requires much equipment. The milliohmmeter, on the other hand, is simple to use but does not necessarily give the same results. The comparisons given below illustrate the differences between the two and indicate that for many purposes the milliohmmeter measurements are adequate. Furthermore, it is possible to estimate the $\Delta V/\Delta I$ values from the milliohmmeter readings.

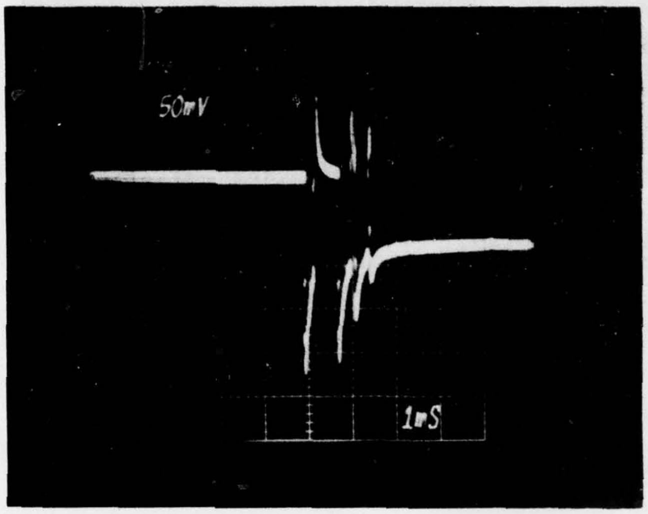
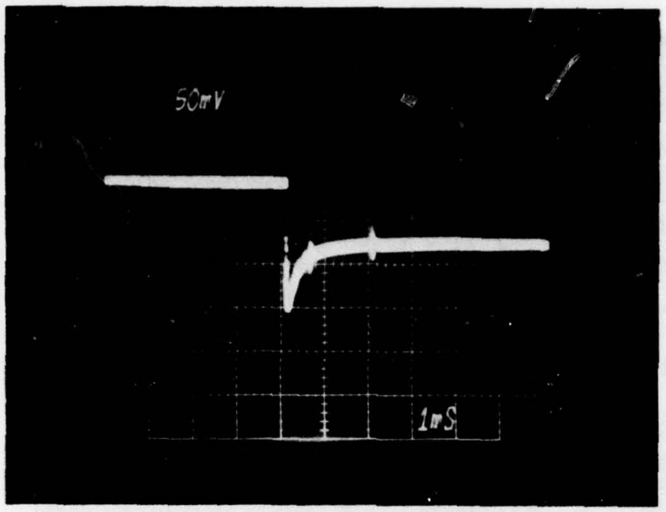


Fig. 1: Initiation of 100A discharge by solenoid operated switch. Lower photograph shows current and the upper one the voltage drop across one cell.



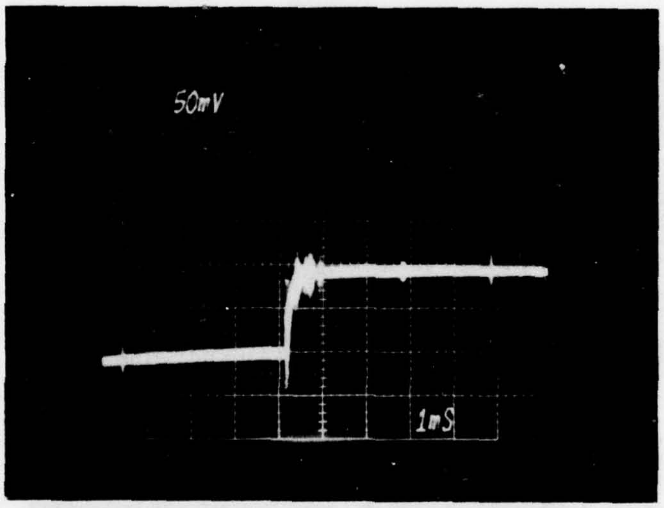


Fig. 2: Initiation of 100A discharge by SCR. Lower photograph shows current and the upper one the voltage drop across one cell.

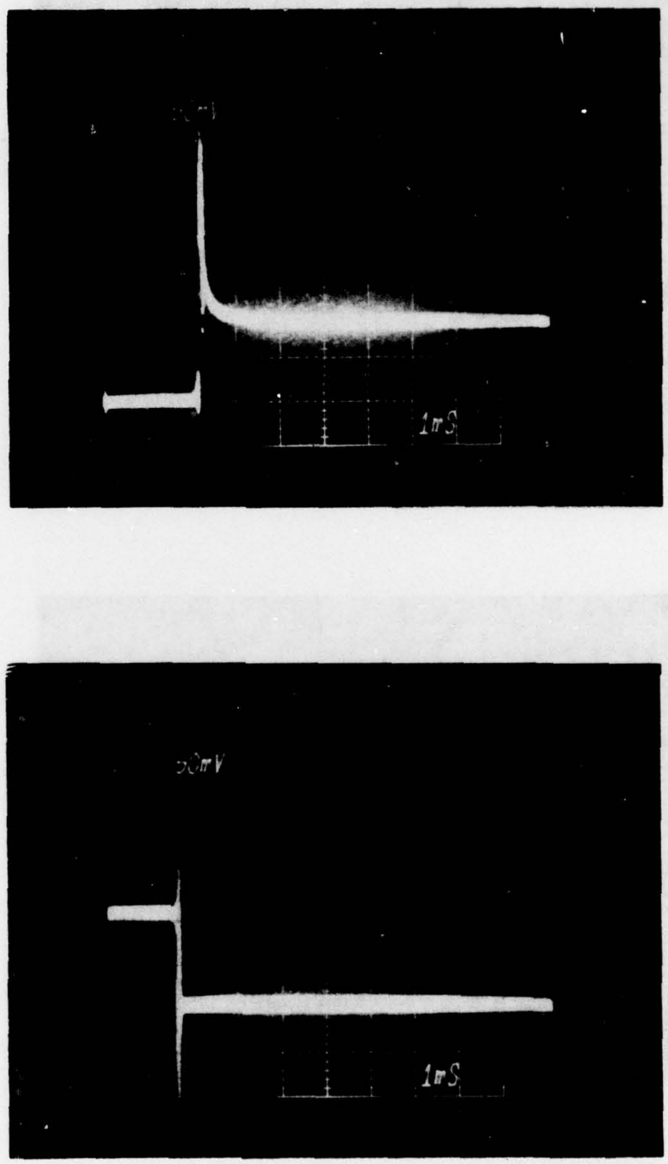
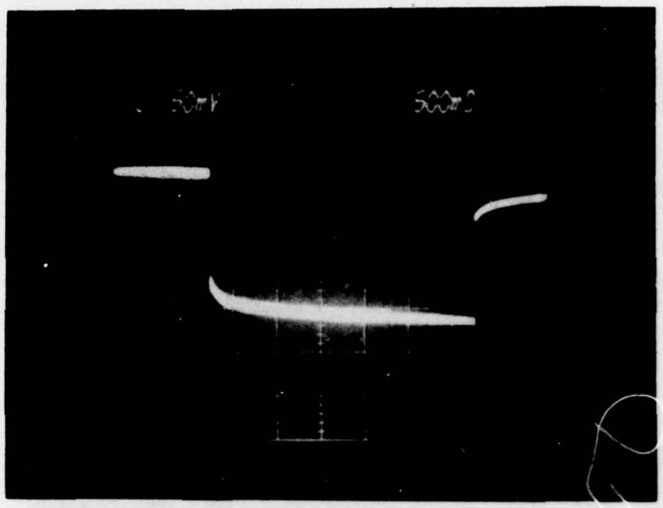


*Fig. 3: Termination of a 100A discharge.
The lower photograph indicates current (zero after the vertical trace) and the upper one shows the voltage rise across the cell.*



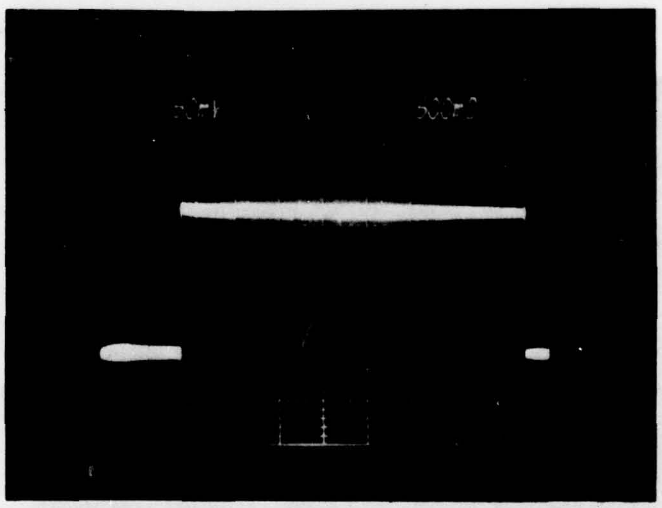


Fig. 4: 100A discharge showing both the initiation and termination of the pulse. The lower photograph shows current and the upper one shows the voltage drop across the cell.

Figure 5 shows resistance measurements on ten fully charged 22-Ah cells at room temperature. The points on the lowest curve indicate the values obtained by use of the ΔV/ΔI method. The middle curve shows the corresponding values obtained by milliohmmeter measurements. On the average these are about 40% higher than the results obtained by the ΔV/ΔI method (the lowest difference is 34% and the highest 49%).

The uppermost curve in the figure shows the resistance of these cells in the discharged condition as measured by the milliohmmeter (there is no difficulty in using the milliohmmeter on discharged cells). These values are, on the average, about 15% higher than when the cells are fully charged.

The above examples indicate that, at room temperature, milliohmmeter measurements on cells may be expected to be subject to tolerances of 10 or 15%, and the resistances of cells themselves may vary from time to time by 15 or 20% depending on state of charge, electrolyte condition, etc. In addition, milliohmmeter measurements on cells when no dc current is flowing, may be around 40% higher than ΔV/ΔI values. For many purposes these tolerances are acceptable and, for estimating high rate performance, applications of a correction factor to compensate for the 40% excess is also usually adequate.

The above correction factor, however, applies only at room temperature. Figure 6 shows resistance determinations for four cells at three different temperatures. At +25° and at -20°C, the milliohmmeter measurements are higher than the ΔV/ΔI values. But at -40°C the reverse is indicated. Presumably, at some temperature between -20°C and -40°C, the two methods give identical results.

The above factors deal with the absolute accuracy. Much of the time in ordinary battery maintenance work, cell to cell comparisons are adequate and absolute accuracy is less important. In such cases the milliohmmeter can be used with no further concern regarding comparison with ΔV/ΔI values.

The milliohmmeter is most conveniently used when the battery being measured is not under load. However, if large dc currents are flowing (see Appendix II) a factor not discussed above, appears. The values indicated by the milliohmmeter, which at room temperature and on open circuit are significantly larger than the ΔV/ΔI values, decrease as the dc current increases.* Typical results are shown in Figure 7. It is seen that the milliohmmeter readings approach the ΔV/ΔI values more closely as the dc current becomes very large.

It seems possible that an explanation for this behaviour is as follows. At room temperature the 1000 Hz milliohmmeter test current distribution through a nickel/cadmium cell is more restricted than the high dc current. The instrument therefore measures the higher resistance path configuration. However, when the two currents flow simultaneously, the milliohmmeter ac current tends in part to become a modulation of the dc current.

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* This observation was reported previously (8) before the varying relationship to the ΔV/ΔI values was observed.

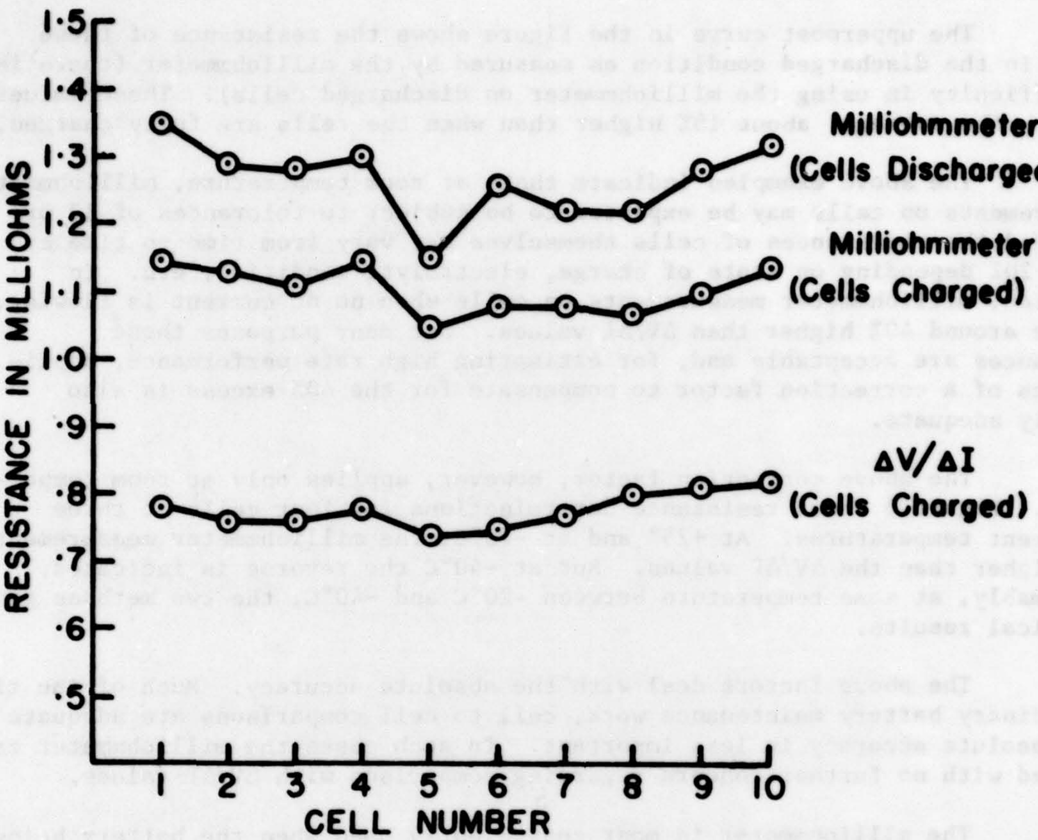

Fig. 5: Comparison of milliohmmeter and $\Delta V/\Delta I$ measurement.

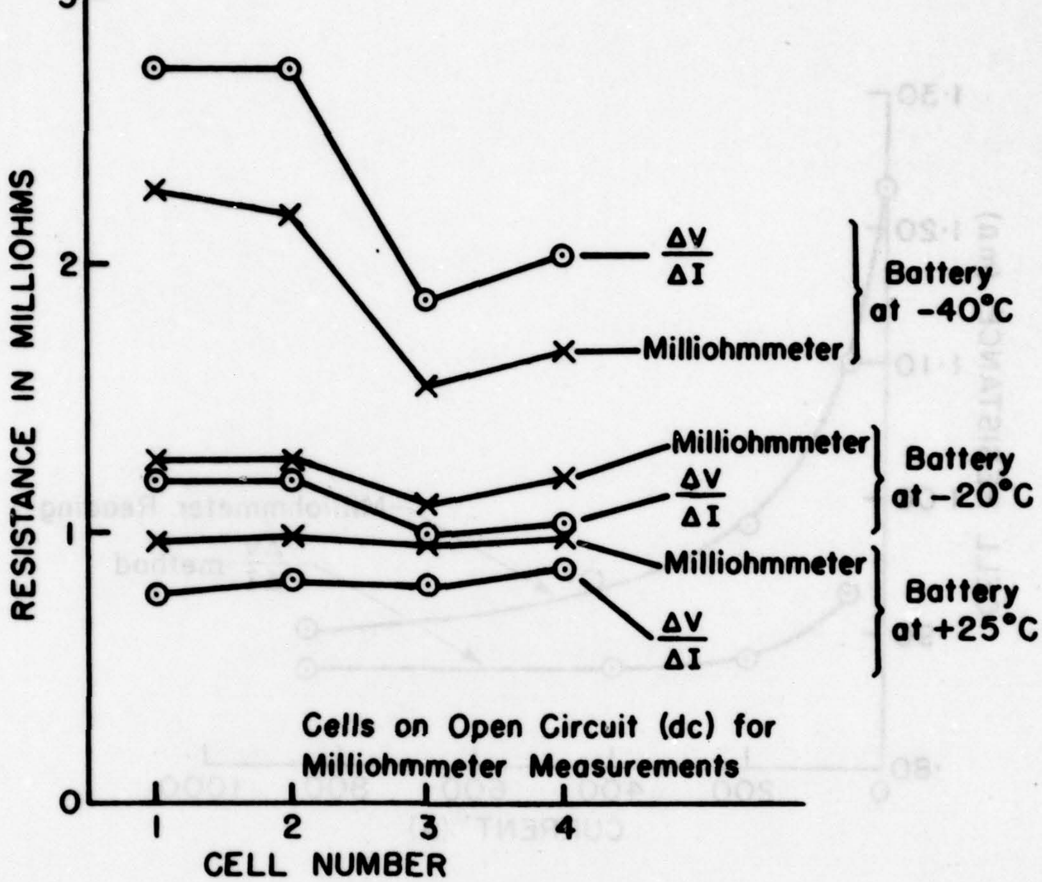

Fig. 6: Battery temperature effects on milliohmmeter measurements.

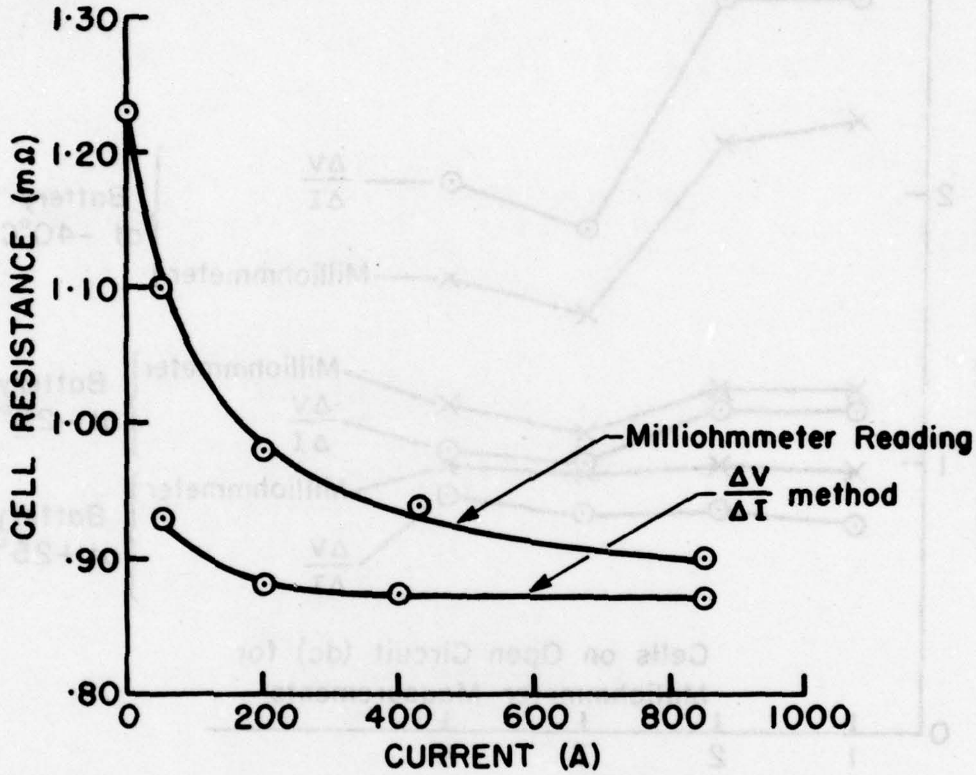

Fig. 7: Milliohmmeter vs ΔV/ΔI during discharges.

Consequently, its distribution tends toward that of the dc itself and hence the lower resistance of this more extensive path configuration is indicated.

EXAMPLES

The following experiences in the laboratory have been selected to illustrate a variety of situations in which routine resistance measurements on the cells of aircraft batteries could prove useful.

MANUFACTURING DEFECT

A new 34 Ah battery was being readied for simulated engine cranking tests. Routine resistance measurements with the milliohmmeter showed cell resistances of approximately 1 mΩ each. Two cells, however, were distinctly higher (1.16 mΩ and 1.32 mΩ respectively). This aroused suspicion so the two cells were monitored closely. The first high rate test gave 735A peak current. The voltages of the two cells in question were lower during the discharge than those of the other cells and were somewhat erratic. Subsequently, it was noted that the resistance of the two cells varied erratically from measurement to measurement on open circuit. Another high rate test with the same load as previously gave only 560A peak. The two cells were replaced and more tests were carried out. Peak currents of 780A were now obtained and erratic behaviour ceased.

In the above case the two defective cells (poor tab welding is suspected) resulted in a current reduction of as much as 14% in cranking experiments as well as in erratic behaviour. In the field such behaviour might cause considerable trouble before diagnosis of the cause is achieved, but routine resistance measurements readily attracted attention to the offending cells.

DEFECTIVE INTERCELL LINK

A battery was assembled after routine maintenance. Links were cleaned in the normal manner. Screws were appropriately torqued. Routine resistance measurements between links showed most cell resistances to be in the neighbourhood of 1 mΩ. One cell, however, showed 1.8 mΩ. The voltage on this cell reversed during a high rate discharge. Subsequent measurements

showed that the high resistance appeared only when measurements included one of the links with the cell. It was found that the connector screw seated in the hole just as the link was drawn to nearly, but not quite, its proper tightness against the terminal. Use of a shorter screw confirmed the diagnoses.

In the field, engine cranking problems might cause considerable trouble before such a defect would be recognized. A resistance measurement readily drew attention to the area.

CELLS FOR LOW TEMPERATURE USE

During a high rate discharge at low temperature (-48°C) it was observed that although some cells were producing voltages as high as 0.75 volts, several others were negative. This was surprising since at room temperature during high rate discharges these cell voltages remained within 40 millivolts of each other. Resistance measurements (milliohmmeter) at room temperature gave values between 0.68 mΩ and 0.80 mΩ. The reasons for this change in range (1:1.18 at room temperature to 1:1.88 at -48°C) were not determined. However, their implications in low temperature high rate operation are obvious from the above data. If it were necessary to select cells for low temperature applications, this could readily be done with the aid of milliohmmeter measurements at the temperature required.

Measurements on the two best and the two poorest cells in the above example are given in Table I for illustrative purposes. It may be noted that although at room temperature, Cell 1 resistance was relatively high, this was not so at low temperature.

TABLE I

Scatter of Cell Resistances at Low Temperatures

Cell	Room Temperature Resistance	-48°C Resistance	-48°C High Rate Discharge Voltage
1	0.80 mΩ	1.22 mΩ	+0.74 V
4	0.69	2.01	-0.11
8	0.68	1.80	-0.19
19	0.77	1.07	+0.75

SELECTION FOR LOW GAS ENTRAPMENT

During overcharge the gas bubbles in the electrolyte restrict the cross-sectional area available for current flow through the cell and hence increase its resistance. After generation of gas ceases, the resistance falls again as the bubbles escape. It has been found, however, that some cells may retain significant quantities of gas for extended periods of time. Such cells would, of course, perform more poorly in high rate applications. In critical cases it may be desired to eliminate such cells. They may be readily identified by milliohmmeter measurements in either of two ways. If such measurements are made prior to the onset of gassing and again some time after charging has ceased, say on the following day, anomalous increases in resistance probably indicate gas entrapment. Another, more positive, method is possible if a vacuum source is available. In this case resistance measurements are made on all cells several hours after termination of charging. A vacuum is then applied to each cell for a few seconds. (This may conveniently be done by use of a vent cap modified by removal of the vent plug and the insertion of a suitable tube for connection to the vacuum source.) The resistance of each cell is then measured again. Significant changes indicate gas entrapment.

Data on four cells in a battery which illustrates the above are given in Table II. The first set of figures shows milliohmmeter measurements made several hours after the end of a charge period.

TABLE II

Gas Entrapment Effects on Resistance of Cells

Cell No.	Ohmmeter Reading	Ohmmeter Reading After Vacuum Application	Decrease
1	1.61 mΩ	1.46 mΩ	9%
2	2.19	1.64	25
3	2.15	1.65	23
4	1.50	1.46	3

On a subsequent cycle this battery was subjected to two high rate discharges, some 16 hours after charging was terminated. Both discharges used the same (constant) load. Each discharge was of 5 seconds duration with a 10 minute rest period between runs. During the rest period a vacuum was applied to each cell vent for a few seconds. Cell voltages were measured immediately before each discharge, under load near the end of the discharge,

and immediately after the end of each discharge. The results for the four cells discussed previously are shown in Table III.

TABLE III

Gas Entrapment Effects During High Rate Discharges

Cell	Before Vacuum Application			After Vacuum Application		
	Before Discharge	During Discharge	After Discharge	Before Discharge	During Discharge	After Discharge
1	1.336 V	+0.170 V	1.198 V	1.318 V	+0.060 V	1.190 V
2	1.330	-0.024	1.200	1.310	+0.412	1.216
3	1.332	-0.020	1.200	1.314	+0.402	1.216
4	1.340	+0.466	1.220	1.310	+0.402	1.214

It may be seen that the current increased after vacuum application in spite of the fact that the battery was now slightly discharged. More significant is the fact that with the gas entrapped, cells 2 and 3 actually gave negative voltages, i.e. they hindered rather than contributed to the battery performance. The cells could readily be identified by the milliohmmeter measurements given above.

CONCLUSION

The concepts involved in the measurement and interpretation of resistance in batteries are more complex than in other areas in the electrical field. However, the resistance in batteries plays a significant role in high rate discharges, and the measurement of cell resistance is a useful method for detecting conditions of concern in battery maintenance. The $\Delta V/\Delta I$ *method* of measuring resistance requires considerable equipment, and some judgement in selecting measurement points on the recorder traces, but within reasonable tolerances, gives the true values applicable to high rate discharges. The milliohmmeter method requires care in technique. For some purposes, the measurements obtained by use of the milliohmmeter require care in interpretation. However, the ease with which the measurements can be made renders this instrument a very useful tool in battery maintenance and research.

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APPENDIX I

CONNECTORS AND TERMINATIONS IN MILLIOHMMETER

Under the conditions of the laboratory at DREO, it was found that the test lead terminations supplied with the milliohmmeter were not convenient for use with nickel/cadmium aircraft batteries, and that after frequent exchange of lead types the connectors provided became unreliable. Consequently, special leads were made up and a more reliable connector* was installed on the chassis of the instrument.

Various types of terminations were provided on the new leads to match the particular requirements of the laboratories. Paramount is the need to minimize danger of short circuits between the crowded cell interconnectors of the typical aircraft battery. For illustrative purposes the following are described:

(a) The current leads are terminated with spade type lugs suitable for inserting below the hold-down screws of the battery terminals. The sense leads are provided with probe tips on the ends of insulated handles several inches long (see Appendix II for measurement practices).

(b) All four leads are terminated with banana type plugs. Spade type lugs whose lead acceptance parts are of appropriate dimensions to receive the banana plugs are mounted on all cell terminals below the battery terminal hold-down screws.

* Winchester M5P and M5S were used.

APPENDIX II

MILLIOHMMETER TECHNIQUES

(a) When individual cells in a battery are to be measured, it is convenient to attach the current leads of the milliohmmeter to the battery terminals (i.e. across all of the cells simultaneously) and leave them there until all of the measurements have been completed. This is so because the test current provided by the milliohmmeter is a constant current. The sensing leads may then be more rapidly moved from cell to cell as the measurements are made. This method applies only if no load is simultaneously connected to the battery.

(b) If milliohmmeter measurements are to be made on a cell or battery which is simultaneously connected to an external circuit, precautions must be taken to ensure that the test current is in fact flowing through the desired cell or cells. For example, suppose a battery, whose internal resistance if 20 mΩ, is discharging through an external load of 20 mΩ. If the milliohmmeter current leads are connected across the battery also, only half of the test current would flow through the battery. Measurements on a single cell in the battery would then give only half of the value that would be indicated if all of the test current flowed through the cell. This effect can be minimized if the milliohmmeter current leads are connected across only the cell being measured, or if other precautions are taken to minimize test current flow through the external circuit (7).

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13. ABSTRACT

The measurement of resistance in nickel/cadmium aircraft batteries can be very useful in assessing quality for high rate applications and in identifying various problems. Frequently, measurements on individual cells are required. For many purposes, measurements can easily and rapidly be made with a milliohmmeter. However, for some purposes determination from appropriate voltage and current measurements may be preferred. This paper discusses both methods and elaborates associated precautions and interpretations. Examples from laboratory experiences are given.

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